[0056] Fig.7A schematically shows a third embodiment of the cross-polarizer.

[0057] Fig.7B schematically shows a fourth embodiment of the cross-polarizer.

[0058] Fig.8A schematically shows a fifth embodiment of the cross-polarizer (with spatial light modulators).

[0059] Fig.8B schematically shows a sixth embodiment of the cross-polarizer (with spatial light modulators).

[0060] Fig.9 shows optional foldings in the light path of the cross-polarizer.

[0061] Fig.10 schematically shows a seventh embodiment of the cross-polarizer (made of 4 MacNeille-PBSs).

[0062] Fig.11 schematically shows a eighth embodiment of the cross-polarizer (with MEMSs).

[0063] Fig.12A shows the transformation from the second embodiment of the invention into the ninth shown in Fig.12B.

[0064] Fig.12B shows schematically a ninth embodiment of the cross-polarizer.

[0065] Fig.13A shows a compound triangular glass prism carrying an inside thin-film polarizing layer and and outside cartesian polarizing layer.

[0066] Fig.13B shows a compound triangular glass prism carrying an inside cartesian polarizing layer and and outside cartesian polarizing layer.

[0067] Fig.13C shows a similar arrangement as Fig.13B with swapped polarizing vectors.

[0068] Fig.13D shows two glass prisms, each of which carries one cartesian polarizing layer.

[0069] Fig.13E shows a single glass prism, which carries two cartesian polarizing layers with different polarizing vectors.

[0070] Fig.13F shows two glass prisms, each of which carries one cartesian polarizing layer.

[0071] Fig.13G shows a four-armed cross-polarizer made of two compound glass prisms.

[0072] Fig.13H shows a four-armed cross-polarizer made of four glass prisms.

[0073] Fig.13I shows a four-armed cross-polarizer made of differently shaped glass prisms.

[0074] Fig.14A shows a four-armed cross-polarizer (open form) within a body.

[0075] Fig.14B shows a four-armed cross-polarizer (closed form) within a body.

DETAILED DESCRIPTION OF THE FIGURES

[0076] Fig.1(A-C) shows a simple and two complex polarizers in 2-channel display systems with polarization rotating reflective spatial light modulators (RLM, e.g. LCoS displays) according to the state of the art. Fig.1A shows a design with a single PBS. Incident unpolarized light (IN) is split by the polarizer P1 in two linearly polarized sub-beams. "S"-polarized light (dotted line) is directed to RLM1 by polarizing reflection. "P"-polarized light (solid line) is directed to RLM2 by polarizing transmission. Light beams incident on the RLM at dark pixels (OFF) are reflected without a change of their polarization back to the axis of incidence. Light beams incident on the RLM at bright pixels are reflected after a rotation of their plane of polarization ("S"-polarized light is rotated to "P"-polarized light and vice versa), and as a consequence these reflected beams are superposed into a common ON-axis. Fig.1B shows a complex polarizer with four identical MacNeille type polarizers P1 to P4. Unpolarized incident light (IN) is split by P1 into two polarized sub-beams. The reflected sub-beam from P1 ("S"-polarization, dotted line) is also reflected at P3 and is incident on RLM1. The transmitted sub-beam of P1 ("P"-polarization, solid line) also transmits P2 and is incident on RLM2. Beams incident on RLM at dark pixels remain unchanged in their polarization and are so reflected back to the axis of incidence (OFF). In contrast, the POPs of beams incident on RLM at bright pixels are rotated by the modulator. They are superposed into a common ON-beam (incident light that transmitted P1 and P2 is now reflected at P2 and P4;

incident light that was reflected at P1 and P3 now transmits P3 an P4). Additional clean-up (CP) polarizers are placed between P1/P3 and P2/P4. These clean-ups reduce polarization impurities in the reflected light beams, they make no contribution to the light path. In the arrangement shown in Fig.1C, where 4 halve-wave plates are inserted between the 4 PBSs, the POP of the beam transmitting P1 is rotated by a first halve-wave plate such that the beam is reflected by P2; the POP of the beam reflected by P1 is rotated by a second halve-wave plate such that it transmits P3. The same polarization rotations are carried out for the ON-beams.

[0077] Fig.2 shows the operational principle of polarizing beam splitters and a definition of layer vector V and normal vector N. Thin-film polarizers like the MacNeille-PBS (P1 in Fig.2A) polarize an unpolarized beam into two linearly polarized sub-beams. Their planes of polarization E2 and E3 are coupled in such a way with the plane of incidence (POI) that the sub-beam derived from a polarizing transmission along the optical axis A1 has a POP parallel to POI ("P"-polarization, E2) and the sub-beam created by a polarizing reflection along the optical axis A2 has a POP perpendicular to the POI (E3). A1 is perpendicular to A2 and each axis has an angle of 45 degree with the normal vector N1. The layer vector V1, perpendicular to POI, and A2 define the POP E3 of the reflected sub-beam; the layer vector V1 and A1 define a plane E1 perpendicular to the POP E2 of the transmitted sub-beam.
While in MacNeille type PBS V1 is always normal to the POI (Fig.2A), in so called cartesian polarizers (e.g. the wire grid polarizer WGP P1 shown in Fig.2B), the POI can be chosen independently from V1. V1 corresponds to the WGP grid structure and together with A2 defines the POP E3 of the reflected sub-beam; V1 and A1 define a plane E1 perpendicular to the POP E2 of the transmitted sub-beam. Each POP of the two sub-beams can (in contrast to the Brewster polarizer of Fig.2A) have an angle with POI of P1 different from 0 or 90 deg.

[0078] Fig.3 shows structural characteristics of the cross-polarizer: three polarizers P1, P2, P3 with the layer vectors V1, V2, V3 and the normal vectors N1, N2, N3 normal to the respective polarizing layer are arranged along two optical axes A1, A2. V1 of P1 and the axis A1 define a plane E1. Axis A2, which is defined by A1 being reflected in P1, and V1 define the plane E3. P2 is arranged such that V2 and A1 span a plane E2, which is perpendicular to the plane E1. P3 is arranged such that V3 and A2 define a plane E4 which is perpendicular to E3. This three-armed cross-polarizer can be extended to a four-armed cross-polarizer using a fourth polarizer P4 with a layer vector V4 and a normal vector N4 along two further optical axes A3 and A4 resulting in four three-arm cross-polarizers (P1,P2,P3), (P4,P2,P3), (P2,P1,P4), (P3,P4,P1).

[0079] Figs.4A,B show functional characteristics of the cross-polarizer: the coupling of a polarizing transmission with a polarizing reflection at two polarizing beam splitting layers, which act complementary on a beam with a given plane of polarization. We call P1 complementary to P2 if they are arranged along an optical axis A1 such that a linearly polarized light beam along axis A1, which transmits P1, is reflected at P2 and vice versa. If V1 and A1 span a plane E1, and if V2 and A1 span the plane E2, and if E1 is perpendicular to E2 as has been shown in Fig.3, a beam with a POP E2 will transmit P1 and be reflected at P2 with maximum efficiency (Fig.4A). Another beam with a POP E1 will transmit P2 and be reflected at P1 with maximum efficiency (Fig.4B).

[0080] Fig.5A shows a three-armed cross-polarizer in a first embodiment of our invention. Three polarizing layers P1, P2, P3 are arranged with their normal vectors coplanar (not shown). The layer vectors of the polarizing layers correspond to the wire grid axes and are aligned such that the structural and functional characteristics outlined in Figs. 3 and 4 are provided. We show the split of an unpolarized incident light beam into two linear polarized sub-beams of different polarization. The sub-beam transmitting

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P1 is reflected at P2 (the arrow seen at P2 corresponds to the projection of the polarization vector of this beam along the optical axis into the polarization layer P2). The sub-beam reflected at P1 transmits P3 (the arrow seen at P3 is the projection of the polarization vector of this beam along the optical axis into the polarization layer P3). After each sub-beam is subjected to a polarizing transmission and a polarizing reflection they are complementarily linearly polarized (which means that their planes of polarization POP are perpendicular if they are defined by a x-y-z-reference system given by the direction of the beam z, the vector x coplanar to the POI and perpendicular to z and the vector y perpendicular to POI and perpendicular to z). Fig.5B shows in a second embodiment the layer vector P1 being perpendicular to the POI and the layer vectors of P2 and P3 being parallel to the POI. In this variation of the first embodiment a single polarization layer comprises both P2 and P3.

[0081] Fig. 6 shows how the equally high polarization contrast of 5000:1 in both channels of the cross-polarizer originates when wire grid polarizers WGPs are used (data of WGP beam splitters taken from Kahn: Doing it with stripes, Private Report on Projection Displays, V7, NO.10, 2001, www.profluxpolarizer.com). Polarization layer P1 with a layer vector perpendicular to POI (and, correspondingly perpendicular to the drawing plane) is shown as dotted line. The polarization layers P2 and P3 which are complementary to P1 (their layer vectors are in the drawing plane) are shown as solid line. "P"-polarized light (solid thin line) with a polarization vector in the drawing plane maximally transmits P1 (0.885) and is maximally reflected by P2 (0.880, Fig.6A). The complementary "S"-polarized light (dotted thin line) in contrast minimally transmits P1 (0.003) and is minimally reflected by P2 (0.050, Fig.6B). We can calculate a polarization contrast: an incident unpolarized light beam (combining Fig.6A and 6B) contains after transmitting P1 and reflection at P2 "P"-polarized light (0.885x0.880) and "S"-polarized light (0.003x0.050) in a P/S ratio of 5000:1 (Fig.6E). Fig.6C and Fig.6D show the complementary situation for the second sub-beam. Here, "S"-polarized light

maximally transmits P3 and is maximally reflected by P1 (Fig.6D), while the complementary "P"-polarized light minimally transmits P3 and is minimally reflected by P1 (Fig.6C), resulting in a S/P ratio of again 5000:1.

[0082] Fig.7 shows a four-armed cross-polarizer in a third and fourth embodiment of our invention in a planar arrangement. A fourth polarization layer (P4) expands the three-armed cross-polarizer from Fig.5 to a four-armed cross. In this exemplary arrangement the polarization layers are perpendicular to each other and have their normal vectors coplanar to POI. This 4-armed cross-polarizer includes several 3-armed cross-polarizer functions. A first light path (solid line) couples P1 with the two polarizers P2 and P3, which are complementary to P1. A second light path (dotted line) couples P3 with polarizers P1 and P4, which are complementary to P3. The layer vectors in Fig.7A (open form) are not aligned specifically to the POI. Thus the two light paths (incident light on P1 and P3) result in differently polarized light in both the west quadrant and east quadrant. In Fig.7B (closed form) all four polarization layers meet in one axis. Using layer vectors parallel and perpendicular to the POI the two light paths (incident light on P1 an P3) result in equally polarized light in both the west quadrant (entire left side shown as "P"-polarized light) and the east quadrant (entire right side shown as "S"-polarized light).

[0083] Figs.8A,B show a four-armed cross-polarizer in a fifth and sixth embodiment of our invention with two image modulators. Open form (Fig.8A) and closed form (Fig. 8B) are directly combined with polarization rotating reflective spatial light modulators RLM. In the open form a cross-polarizer (P1,P2,P3) is used to direct incident light towards the two RLMs (IN, "P"-polarized light to RLM1 and "S"-polarized light to RLM2). Light beams incident on the RLM at dark pixels are not modulated, keep their polarization and thus are reflected back to the axis of incidence (OFF). Light beams incident on the RLM at bright pixels are rotated in their plane of polarization (ON); they are

superposed in the left side of north quadrant by a second cross-polarizer (P4,P2,P3). The closed form (Fig.8B) makes it possible to send light both to P1 and P3 using the entire south quadrant. According to Fig.7B, this results for both input cross-polarizers (P1,P2,P3) and (P3,P1,P4) in "P"-polarized light in the entire east quadrant and "S"-polarized light in the entire west quadrant. Two further cross-polarizers (P2,P1,P4) and (P4,P3,P2) are used for superposition. Altogether, for the input into the RLMs and the output of the RLM-ON- and RLM-OFF-light four overlapping three-armed cross-polarizers are used. The closed form (Fig.8B) uses less than 25% of the area needed for the open form (Fig.8A).

[0084] Fig.9 schematically shows optional foldings in the light path of the cross-polarizer. Two polarizers P1 and P2 can act complementary on a linearly polarized beam also if means for folding (M) are introduced in the path (S1) of this beam. Each folding M transforms both the axis of the beam and its POP. Fig.9 shows a beam with a POP E1 (spanned by V1 and S1 at P1) which would be reflected by P1. Its POP E1 is transformed by each folding M to become E1*. Also, S1 is transformed by each folding. If the transformed S1 (at P2) and V2 span a plane E2, which is perpendicular to E1*, P2 will act complementary to P1, the beam with POP E1* will transmit P2. In contrast to many embodiments above, in Fig.9 the normal vectors of the polarizing layer planes are not coplanar. In the shown example, P1 is a MacNeille PBS and P2 is a WGP.

[0085] Fig.10 shows in a seventh embodiment of our invention a folded four-armed cross-polarizer using four MacNeille-type polarizers P1, P2, P3, P4 and two mirror planes (M; shown are total internal reflection prisms TIR) combined with polarization rotating reflective RLM1 and RLM2. The IN-beam and the OFF-beam use a cross-polarizer (P1,P3,P2) with additional means of reflection in each light path. For the superposition of the ON-beams we use a second cross-polarizer (P4,P3,P2) without

additional reflection. This embodiment corresponds to the open form of the four-armed cross-polarizer.

[0086] Fig.11 shows in a eighth embodiment of our invention, a four-armed cross-polarizer in a closed form using reflective RLMs of the digital mirror device type (DMD). These DMDs modulate the incident light (IN) by directing ON- and OFF- light towards different directions without rotating their polarization. DMD1 and DMD2 have identical topology (are the same stereo isomer). They reflect light at bright pixels normal the DMD surface. As there is no modulation dependent change of polarization, this ON-light of both DMDs is superposed and reflected back to the quadrant of incidence. Input POI and output POI have an intersection angle adjusted to the mirror deflection angle of the DMD. Light reflected from dark pixels (OFF) is directed towards a light dump (not shown).

[0087] Figs.12A,B show a two-armed form of the cross-polarizer (ninth embodiment of our invention). The three-armed cross-polarizer of Fig.5B can be converted to a two-armed cross-polarizer by fusion of P2 and P3 and additional folding (M) of each sub-beam (Fig.12B). Both sub-beams created at P1 ("P"-polarized sub-beam in light path S1 by polarizing transmission of the input beam at P1 and "S"-polarized sub-beam in light path S2 by polarizing reflection of the input beam at P1) are folded toward a second polarizer P2 such that the "S"-polarized sub-beam transmits P2 and the "P"-polarized sub-beam is reflected at P2. P2 thus acts complementary to P1 for both sub-beams. Fig.12A shows that P2 in Fig.12B can be understood as a fusion of P2 and P3 in the second embodiment (Fig.5B). As both sub-beams in S1 and S2 are separated only between the two polarizers, this embodiment can be used in 2-channel display systems with spatial light modulators e.g. of the MEMS type which are placed in S1 and S2 between P1 and P2.

[0088] Figs.13A-I show glass prisms with polarizing layers which are configured to built cross-polarizers. Fig.13A shows a cross-polarizer made of a right triangular prism, which comprises two right sub-prisms T1 and T2. Between T1 and T2 there is a polarizing layer P1 of the MacNeille type. The continuous surface of the prism which consists of two surfaces of the two sub-prisms carries a cartesian polarization layer P2/P3 with a layer vector V2 parallel to the base of the prism. Further glass prisms without polarizing layer may be added to the arrangement (see Fig.13A-C) to complete a three-armed cross-polarizer. In Fig.13B P1 is a cartesian polarization layer. Fig.13C shows a similar arrangement as Fig.13B but with swapped polarizing vectors. Fig.13D-F show prism arrangements with cartesian polarizing layers with which cross-polarizers (three- or four-armed) can be built. Two prisms of the types shown in Fig.13D-F suffice to build a four-armed cross-polarizer. Four prisms of the one shown in Fig.13E-F result in a four-armed cross-polarizer which has double polarizing layers (Fig.13H). In Fig.13F the polarization layers are mounted to a lateral surface of sub-prisms T1a and T1b. In Fig.13G a four-armed cross-polarizer is constructed by adding a triangular MacNeille type polarizer to the three-armed cross-polarizer shown in Fig.13A. Fig.13I shows an example of a four-armed cross-polarizer in which the polarizing layers are not perpendicular to each other.

[0089] Fig.14 shows cross-polarizers within a closed body. Fig.14A shows the open form, Fig.14B the closed form of the four-armed cross-polarizer each contained in a single body. Openings can be used to directly mount RLMs (Fig.14B). It is also possible to integrate optical elements as projection lenses L to the body of the cross-polarizer.

[0090] It will be appreciated that whilst this invention is described by way of detailed embodiments, these realizations serve as illustrations of the invention but not as a limitation of the invention; numerous variations in form and detail can be deduced by

those skilled in the art or science to which this invention pertains without leaving the scope of the invention as defined by the following claims: